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REPORT

OF

LYMAN E. COOLEY, LATE ENGINEER
OF THE CHICAGO DRAINAGE CANAL,

ON THE

DEVELOPMENT

OF THE

WATER POWER

OF THE

Des Moines Rapids of the Mississippi
River, Near Keokuk, Iowa,
and Hamilton, Illinois.

Published by the
Keokuk & Hamilton Water Power Co.
Keokuk, Iowa.
1901.

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DES MOINES RAPIDS OF THE MISSISSIPPI RIVER, NEAR KEOKUK, IOWA, AND HAMILTON, ILL.

PUBLISHED BY THE

KEOKUK & HAMILTON WATER POWER CO.,

KEOKUK, IOWA.

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MISSISSIPPI RIVER COMMISSION
PLAT OF DES MOINES RAPIDS
CAPTAIN MASON M PATRICK CORPS OF ENGINEERS

ERRORS AND ADDENDA.

Title page, correct to read, Lyman E. Cooley "*formerly*" Engineer "*and Trustee*" of The Chicago Drainage Canal.

Page 11, first line to read the "*work*" instead of the works.

Page 15, ninth line from bottom should read "*these*" readings instead of those readings.

Page 17, third line to read crest of dam "*due*" to volume, etc.

Page 25, eleventh line from bottom take letter "*s*" out of word considerations.

Page 36, sixth line take out word *line* and insert "*mile.*"

Page 36, "*$14,000.00*" put to right of say.

Page 36, behind $3,200.00 place "

Page 36, behind $7,300.00 place "

Page 36, fifth line from bottom and between substation and three, place " to read as follows, *For substation*, "*three 500, etc.*

Page 36, behind 8,000.00, place "

Page 40, third line from bottom (*factor, 1.155*) instead of 155.

Page 41, in frames, add | "*Year*" "*Steam*" | "*Year*" "*Water*"

Page 43, add "*at*" to addition in 11th line from bottom.

Page 46, twelfth line, the word initation should read "*initial.*"

Page 46, sixteenth line, $35,000 should be corrected to read "*$35.00.*"

Page 48, ninth line from bottom should read "*thousand dollars*" instead of thousand.

Page 51, fourteenth line, James Leffal's should read "*James Leffels.*"

Page 53, tenth line, total, 1,760 "*feet.*"

Page 53, fourth line from bottom, the word designated should read "*designed.*"

Page 56, sixteenth line from bottom should read "*in structures*" instead of instructures.

Page 58, eleventh line, Dalls should read "*Dallas.*"

Page 63, tabular work, volume 1,000 should read "*volume*" only.

P 14095

KEOKUK & HAMILTON WATER POWER COMPANY.

Incorporated State of Illinois.

Offices in Keokuk, Iowa, and Hamilton, Illinois.

DIRECTORS:

Charles P. Birge,
C. P. Dadant,
R. R. Wallace,
Wm. Logan,
A. E. Johnstone,
Edmund Jaeger, Sr.
S. R. Parker.

OFFICERS:

Chas. P. Birge, President,
Keokuk, Iowa.
C. P. Dadant, Vice-President,
Hamilton, Ill.
R. R. Wallace Sec'y and Treas.,
Hamilton, Ill.

This company was organized by citizens of Keokuk and Hamilton, to promote the development of the immense water power of the Mississippi River now lying dormant between Keokuk and Montrose on the Des Moines Rapids. It is a patriotic undertaking by these citizens and not made for private gain. The company has obtained from Congress the required concessions as will be seen by the act of Congress printed in the following pages, and will obtain more if found necessary. Lyman E. Cooley one of the most eminent engineers of the United States, and long connected with the Chicago Drain-

age Canal, has made a most thorough investigation of the probability of this water power lying at our doors and embodied it in his report which will be found herein.

We are now seeking the capital for this project and stand ready to turn over all our rights and privileges to parties possessing the ability to develop this power and pledge ourselves as officers and individually as stockholders, to give our utmost aid to the accomplishment of this purpose and the aid and good will of the twin cities of Keokuk and Hamilton.

The manner of promoting the enterprise as well as the method of development to be wholly determined by the parties interested.

KEOKUK & HAMILTON
WATER POWER CO.

FRANCHISE.

[PUBLIC—No. 43.]

An act granting to Keokuk and Hamilton Water Company right to construct and maintain wing-dam, canal, and power station in the Mississippi river in Hancock County, Illinois.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the assent of Congress is hereby given to the Keokuk and Hamilton Water Power Company, a corporation created and organized under the laws of the State of Illinois, its successors and assigns, to erect, construct, operate and maintain a canal along the east bank of the Mississippi River, between Nauvoo and Hamilton, in Hancock County, in the State of Illinois, to erect, construct, operate and maintain a power station thereon, and to project, erect, construct, operate and maintain a wing-dam five hundred feet into the river from the head of said canal, and to make such other dams and improvements as may be necessary within said limits for the development of water power and the generation, use, and transmission therefrom of electric energy and power at, in, and upon the Des Moines Rapids of the Mississippi River: *Provided*, That the construction hereby authorized do not in any way interfere with the existing low-water channel over the Des Moines Rapids, or with the interests of navigation: *And*

provided further: That until the plans and location of the works herein authorized, so far as they affect the interests of navigation, have been approved by the Secretary of War the canal or other improvements shall not be commenced or built.

SEC. 2. That this Act shall be null and void if actual construction of the works herein authorized be not commenced within three years and completed within six years from the date hereof.

SEC. 3. That the right to alter, amend, or repeal this Act is hereby expressly reserved.

Approved, February 8, 1901.

Proposed Water Power Development of the Des Moines Rapids of the Mississippi River, Near Keokuk, Iowa.

Preliminary Report by LYMAN E. COOLEY.

INTRODUCTION.

The Des Moines Rapids of the Mississippi river are immediately above the city of Keokuk, Iowa, between the states of Illinois and Iowa, with the state of Missouri a few miles to the southwest and beyond the Des Moines river. The Mississippi river here flows to the south in latitude 40 degrees 27 minutes north and longitude 91 degrees 22 minutes west.

The rapids proper lie in a rock gorge cut in the Keokuk limestone, quite uniformly seven-eighths mile wide between bluffs and twelve miles in length between Montrose and Keokuk. The river bed itself is generally three-fourths mile wide and the floor is remarkably uniform in elevation across the width from shore to shore, so uniform as to be practically covered at low water.

The declivity at standard low water may be taken at 23.8 feet and at extreme high water at 15.7 feet. The slope is not uniform being but 3.6 feet at low water and 4.2 feet at high water over the upper 4½ miles between Montrose and Nashville. Below Nashville, the slope is broken at low water by "chains" of more resisting rock.

The United States Canal extends along the west, or Iowa, shore between Nashville and Keokuk and has three locks, one at either end and one intermediate. It was not found necessary to carry this canal over the entire rapids, and the west shore presented the most favorable conditions for canal construction.

The extreme range for the twenty years, 1881-1900, at Nashville, is 12 feet and at Keokuk, 20.7 feet. The standard low water volume is taken at 20,000 cubic feet per second and the extreme high water volume at 372,500 feet per second. The drainage area above Nashville is taken at 111,246 square miles, the mean volume for 20 years, as deduced from the mean gauge curve, is 62,000 feet per second, corresponding to an average run-off of about 7.5 inches from the entire basin, and the mean fall from Nashville to Keokuk is 17 feet.

GOVERNING FEATURES.

Several features are at once evident as determining the general project for developing the water-power of the Des Moines Rapids.

1. The range in fluctuation from low to extreme high water at the foot of the rapids is much greater than at Nashville, 1.7 times, (nearly the same at Montrose) while it is double that at intermediate points, as Sandusky. This great variation makes wide changes in fall at different stages of water and drowns the declivity of the lower rapids in high water. The upper part of the rapids is therefore most efficient and yields better results for the expenditure.

2. The head of water must be carried by canal along the east shore as the west shore is now occupied by the navigation canal. No advantage commensurate with the cost is obtained by heading this canal above Sonora Point, nearly opposite Nashville,

owing to the relatively flatter slopes up stream. The presence of Cheney creek and the shore bar fixes the lower end of the canal in this vicinity, and the bight in the shore line facilitates the construction of a broad basin and provides room for power stations at the lower end. The site is also favorable for construction on account of the high elevation of the rock in the river bed.

3. As a canal and wing-dam project, no reduction in cost in proportion to reduction of power is likely to be effected by selecting other initial and terminal points. There is a considerable low water fall from the proposed power site to the bridge, but owing to the higher rock and less favorable conditions of the east shore as compared to the west shore, the development of this fall by means of a tail-race will not be justified. The location of the canal is restricted as closely to the east shore as practicable owing to the proximity of the low water channel over the rapids.

4. Additional power is most cheaply produced by means of a dam from the head of the power-canal at Sonora Point to the head of the navigation-canal at Nashville. Little cost is added to the canal as the banks are necessarily carried to the high-water limit in the wing-dam project. Such dam utilizes the fall of the rapids above in the most practicable manner, and may utilize part of the range above Montrose, but its height is limited by the back-water effect or overflow at the bank full stage, generally 10 to 12 feet above low water in the big bottoms above Fort Madison. Fortunately the land to be effected is largely limited to narrow margins below Fort Madison, so that a considerable height is permitted. Local conditions, as high water at dam site, and the head works of the navigation canal and

the length of dam are factors for consideration. The dam puts under control the entire low water flow of the river.

5. The power created by the dam and canal are so large that its increase by the construction of a tail-race to utilize the low-water fall below the site of the power station will be eventually justified when the demand for additional power shall warrant. This will be a work of some magnitude, but no additional installation will be required.

6. The progressive development above indicated lends itself to an economical construction program without material loss, provided the design is properly made at the outset, and it is a rational procedure in harmony with the probable market for the power.

7. Other projects, as by the construction of a dam at an intermediate point on the rapids, are practicable, but involve material changes in the upper reaches of the navigation canal and the preliminary development by wing-dam would be less effective. A dam at the lower chain, near the foot of the rapids, would entirely do away with the navigation-canal and substitute a single lock, but would not permit a progressive development. Some such design might have great merits were there no navigation canal or were same in control of the Power Company, but in view of the actual situation, the working up of such schemes have not seemed justifiable.

8. The carrying out of a dam project is in harmony with public policy as affording a material improvement of the navigation of the river for some 25 miles above the dam site and such development may form part of some ultimate project for the radical improvement of the river.

THE PROJECT.

It is apparent that the design must be worked out as a whole and in the order of dam, canal and tail-race; while the actual execution will be progressive, as demanded by the needs for power, and in the order of canal, dam and tail-race. The conditions to be produced by a dam are essential to a proper design of canal, and the tail-race conditions are essential to a proper installation, in order to avoid great waste and imperfect results in a progressive scheme.

THE DAM.

The purposes of a dam are two-fold :

1. The low water volume is fixed in amount and the power available is measured by the head that can be produced. The higher heads lessen the cost of the installation per unit of power and, within limits, the installation is also more efficient. The higher the dam the less the excavation in the canal for a given volume of water, and the actual cost is divided by a larger horse-power.

2. The dam also provides a large pond, some 25 square miles of surface as actually designed, which is a very practical storage reservoir at low water. In a general market supply a portion only of the power will be continuous through the 24 hours, and a few inches of fluctuation will enable the variable powers to be largely increased. It is probable that the actual horse-power hours that could be sold under commercial conditions would be increased by not less than 50 per cent over what would be feasible without a reservoir and with the same heads and where the maximum is limited by the actual flow of the stream at the time of use.

While the height of dam contributes to both the foregoing objects, there are positive limitations.

Backwater in time of floods should not materially increase the overflow of extensive bottom lands and damage large raparian interests. The shore margins of the power canal and the height of the outer bank of same are important considerations. The guard lock at the head of the navigation canal is also a consideration, but the walls can be readily raised.

The foregoing considerations call for a minimum range on the dam, or the high water as little as may be above the crest. This may be accomplished through length of crest and by such form of crest as will give the least depth for a given volume of water. Any dam that effects low water level by a considerable amount will raise high water sensibly; any dam that does not reach to the high water limit will have the depth over same increased by drowning, and a dam above high water will have free discharge and the minimum range, though drowning to one-third the depth on crest does not have a large effect.

A consideration of all these matters in conjunction with the actual site, the up-stream slopes, the situation at canal head, the position of the low water channel, progressive development and the initial use of a part of the dam as a wing-dam, determines the following:

Dam crest to be 10 feet above the zero of the Nashville gauge; to be 6,000 feet long; to spring from the outer canal bank 2,000 feet below Sonora Point and to gradually swing out from shore but not to infringe on the low water channel at the 2,000 foot point, thence on a course more directly across the river to the head of the navigation canal. The first two thousand feet opposite and below Sonora Point, partially constructed, is virtually a wing-dam and extension of the power canal.

The depth on the crest of this dam is estimated

at 6.7 feet in extreme flood without use of canal. With canal in use and such weirs and bear-trap as provided for the basin, the depth should never exceed 6.0 feet. These figures are based on Cornell university — Section No. 19. (See Transactions American Society of Civil Engineers, XLIV, p. 284, 1900). The particular form of crest proposed has not been experimentally determined, but it is believed that it will give more efficient results and that the limiting depths will be from 0.3 to 0.5 feet less.

The extreme height on crest is therefore taken at 6.0 feet, or 16 feet on Nashville gauge, which is 3.9 feet above extreme high water and 2.1 feet above top of guard lock.

The effect of backwater has been a matter of expert evidence ever since dams were built and is usually exaggerated. Its determination is peculiar to each case and is one of the most obscure problems in hydraulics. A preliminary consideration gives the following limits : In extreme high water the surface will be raised at Montrose by 2.1 feet (half the slope is drowned out); at Fort Madison by 0.8 foot; at Dallas by 0.4 foot, and practically nothing at Burlington. The area of marginal lands are about 550 acres above the high water of the United States Engineer's profile, and these lands are not of great value.

The water has ranged above 8.2 feet on the Nashville gauge for 167 days in 20 years (1881-1900), corresponding to a flow of about 200,000 cubic feet per second. The height on dam is taken at 4.37 feet, (4.0 feet with canal in use). The water is not raised above the United States Engineer's high-water line at Montrose or above. It is raised above the stage corresponding to 8.2 feet on the Nashville gauge as follows : Montrose 3.2; Fort Madison 1.3; Dallas 0.6.

At low water corresponding to 20,000 feet per

second and 0.1 feet on the Nashville gauge, no water over-dam, the estimated raising is as follows: Montrose 6.4; Fort Madison 4.4; Dallas 1.75; the effect disappearing practically half way between Dallas and Burlington. The area of water, as affected by dam, may be taken at 25 square miles and this constitutes the reservoir aforementioned.

THE CANAL.

The canal proper begins some 2,000 feet below the upper side of Sonora Point, though considerable excavation is required over this stretch to produce an ample water-way from the low water channel of the river and adjacent to that portion of the dam which is to be partially constructed at the outset and used as a wing-dam. It is believed that the shore configuration and the treatment at this locality will largely avoid the running of ice and drift into the canal.

The canal is designed to carry 20,000 feet per second at standard low water at the level of the crest of the dam, and the prism will have a section of 7,050 square feet, a depth of 20 feet (10 feet below zero of Nashville gauge) and a bottom width of 335 feet, with a wall on the river side and the slope of the bank, trimmed in localities, on the shore side. The slope in canal bottom is made 0.8 foot in five miles to the head of the basin and is computed for the conditions when the river is carrying the mean volume.

The high water level in canal is taken at 6 feet above the dam crest, giving a section of 9,300 square feet. The volume required through the canal at this stage is about double that at low water and the slope therefore is considerably greater, but the extreme is of rare occurrence and short in duration.

The location of this canal is closely restricted to the shore line, owing to the proximity of the low water channel throughout most of its length, and little latitude is allowed for variation to reduce amount of excavation. This excavation is practically all rock and this fact dictates the type of river bank which is designed as a masonry wall carried to the high water line and backed by the waste excavation and protected on the river side by slope paving and a toe-wall. No more efficient or cheaper type of construction has suggested itself and it has the merit of permanent work. The surplus excavation not otherwise required should go into the roadway on the shore side.

The basin begins at the fifth mile and extends for three-fourths mile, gradually widening to one-fourth mile at lower end about one-fourth mile above Cheney creek. The outer line is fair with the line of the shore bar below and does not encroach on the proper flowing channel of the river. A bear-trap section is to be constructed in the outer wall to run off ice and drift that may find their way through the canal and for producing a flushing current in the canal at low water, and high water overflow weirs can be added if found desirable.

The lower end of the basin is designed to be closed by the walls required in connection with power stations and will form part of the installation.

It is practicable to divert Cheney creek to a location one-fourth mile south and extend the basin one-fourth mile, (to the present mouth) on the shore side and by one-third mile on the river side. This would materially reduce the excavation in the tail-race when the same shall be undertaken. There may be other determining conditions, however, as the development of local industrial establishments

and the sites therefor which will have a bearing on the matter.

The initial uses of the canal for a wing-dam proposition does not suggest material changes except in the first installation. Extreme high water is within four feet of the top of the wall, or the level with the dam. The low water prism is relatively less efficient, as the water is some 0.3 foot lower in elevation at Sonora Point than at Nashville, and so large a proportion of the flow, drawn off through the canal, will lower it about a foot more, so that the depth flowing in the canal will be less than nine feet and the slope in the canal will be excessive. At normal low water the conditions are more satisfactory. To remedy the conditions would require an excessive amount of excavation which does not seem justified. The matter is significant as showing that the practical difference between a canal for a wing-dam proposition only involves a bank four feet less in height and less shore grading with surplus excavation, than for the dam which raises low water in the river by some ten feet.

The canal is to be provided with piers and a bridge at the entrance and so executed as to facilitate the placing of caissons or a coffer-dam, should same be required for any purpose.

THE TAIL-RACE.

The execution of a tail-race is costly owing to the continuously high level of the bed-rock along the east shore from the power station to the bridge. It should add some 30 per cent to the effective low-water head and increase the available power by that amount, but the execution of the tail-race on the basis of wing-dam requirements will probably com-

plicate the works when it becomes necessary to enlarge for the requirements of the dam proposition, unless it be found feasible to remove this rock economically by some form of dredging machine. The construction of the dam will be a more useful application of the money, as the power will be multiplied thereby more than four times.

After the dam development, the tail-race will add 15 to 20 per cent to the low-water head and to the constant available power, without practically other additions to cost, and it can be undertaken when the market demands the additional power. This race will be built behind the power station and alongside the shore bar to the vicinity of the bridge and be guarded by a high-water bank formed from the excavated material and extending down from the outer corner of the basin. This bank does not need to be tight in the sense of the canal bank proper and does not require the same care in construction.

The effect of the tail-race diminishes from nearly four feet at low water to less than one foot at extreme high water. This is due to the drowning at the lower end of the rapids as before noted.

The consideration of the tail-race is material at the outset in view of its bearing on certain features of design for the power stations and their installation.

THE EFFECTIVE HORSE-POWER.

The effective horse-power is measured on the turbine shaft and involves three factors : the volume of water, the available head or fall and the efficiency of turbines.

If the turbine efficiency be assumed at 80 per cent. then 11 cubic feet of water per second, or one

foot falling 11 feet, will generate one effective horse-power. In preliminary calculations, 12 feet may usually be taken for the gross head, or an efficiency of 73 per cent, the allowance of 7 per cent being made for slope in canals, races and for other losses.

The zero of the Nashville gauge is 19.1 feet above the zero of the Keokuk gauge, and standard low water is taken at 20,000 cubic feet per second which is equivalent to one foot below zero of gauge at Keokuk. A dam 10 feet high on the Nashville gauge will therefore give a gross fall of 30.1 feet or 50,000 horse-power. Again 50,000 horse-power calls for an effective fall of 27.5 feet, which allows 2.6 feet for loss in canals, races, etc. As will appear later, these losses are within the limits of the design.

THE VOLUME.

The determinations of volume rest on measurements by United States Engineers of low stages at Burlington in 1879, and a complete series at Hannibal in 1880-1. A painstaking study of gauge relations for Hannibal, Warsaw, Keokuk, Nashville and Burlington, has been made for the purpose of determining the normal ratios and the equivalent volumes, especially on the Nashville gauge, this gauge being free from backwater effects of tributaries below and located at the controlling point of the problem. Such determinations are subject to error, especially at low and high water limits, through change in plane due to a shifting river bed, through varying overflow conditions and through tributary action, but intelligent study can largely discount such effects.

The normal equivalents may be tabulated as follows:

NASHVILLE GAUGE.	VOLUME SECOND-FEET.	KEOKUK GAUGE (EQUIVALENT)	FALL.
0	19,000	-1.26	20.36
1	30,100	1.36	18.74
2	43,000	3.20	17.90
3	58,200	4.93	17.17
4	77,300	6.65	16.45
5	99,800	8.37	15.73
6	126,800	10.07	15.03
7	158,100	11.82	14.28
8	193,600	13.54	13.56
9	233,600	15.26	12.84
10	276,100	16.99	12.11
11	320,700	18.56	11.54
12	367,700	19.67	11.43

Standard low water is taken at 0.1 Nashville, and 1.0 Keokuk, corresponding to a flow of 20,000 and a fall of 20.2 feet. Extreme high water is taken at 12.1 Nashville, and 19.77 Keokuk, corresponding to a flow of 372,500 and a fall of 11.43 feet. The actual gauge reading at Keokuk may differ from the equivalent above owing to the unsystematic relations of the Des Moines river discharge which produces variable backwater effects. In a broad average the gauge at Keokuk will range somewhat above the equivalent. Such determinations are approximate and have not the value of direct measurements at the site though the regimen of the river is comparatively stable. They are useful as disclosing the habits of the river over long reaches; they are the best data that can now be produced, and they are sufficiently close for all present purposes.

In connection with the foregoing the gauge records for the 20 years from 1881 to 1900 inclusive, for

both Nashville and Keokuk, have been reduced. Such a period is usually considered sufficient for reliable interpretation. The mean gauge curve has been made up from the mean for each day in all the years, and the extreme high and low water curve from the extreme for each day in any year. These curves represent the normal and the extreme expectation and they furnish as well a record of mean and extreme conditions.

Some of the significant results may be exhibited as follows:

NASHVILLE GA'GE	VOLUME SECOND FEET	CONDITIONS IN 20-YEAR PERIOD.	KEOK'K GAUGE (actual)	FALL
12.1	372,500	Extreme H. W., U. S. Engrs.	19.6	11.6
10.0	276,100	Above for 43 days	17.97	11.13
9.0	233,600	Above for 105 days	15.97	12.13
8.2	201,300	Above for 167 days	15.16	12.14
7.6	178,800	Average high water	14.1	12.6
5.9	129,900	H. W. mean gauge curve	10.4	14.6
3.21	62,000	Apx. mean volume	5.44	16.87
2.98	58,000	Mean gauge	5.06	17.02
1.6	37,600	Below for 2,414 days	2.47	18.23
1.2	32,500	L. W. meam gauge curve	1.3	19.0
0.46	23,750	L. W. average extreme	-0.04	19.6
0.30	22,000	Below for 67 days	-0.53	19.93
0.10	20,000	Below for 9 days	-1.53	20.73

The mean volume above given will be slightly increased by summing the yearly curves, but the average run-off will not greatly exceed 7.5 inches on the 111,246 square miles of area above Nashville, as hereinbefore noted.

A volume of 200,000 feet, or 8.17 on Nashville gauge, was exceeded in 1881-2-3-4-5-6-8 and 1892-3-7.

Mean high water occurs (Nashville) on May 7, and mean low water on December 9, and as given in

above table. There is also a low water of September 6, of 1.5, or 36,300 feet, and a crest on October 24, of 2.4, or 48,600 feet. The hydrograph, or gauge curves, show the variations graphically for the entire year.

The quantities heretofore given are based on an open river. The effect of an ice cover is to increase the frictional resistance, thus increasing the cross section of the stream and raising the gauge. The thickness of the ice also raises the gauge. Only direct observations and known thicknesses of ice will enable a local gauge equivalent to be determined with any certainty.

The transfer of winter discharges from Hannibal indicates that the general effect of an ice cover at Nashville is to make the gauge reading 1.4 feet for the standard low water discharge of 20,000 cubic feet, a rise on gauge due to ice of 1.3 feet.

The report of the United States Deep Waterways Commission, 1896, gives an ice record of 20 years at Montrose and of 26 years at Keokuk, and the averages are as follows :

Montrose, January 3, February 20, or 48 days.
Keokuk, January 5, February 25, or 51 days.

The Nashville mean curve gives an elevation of 2.3 for January 3. and 2.7 for February 25, and the elevations at Keokuk are substantially concurrent. Those readings are so much in excess of the equivalent of 20,000 feet, that the average winter conditions may be assumed to give a safe margin.

There are probably winter conditions in some years that give less than 20,000 feet, but what the minimum may be or how long continued is a matter of speculation. Such minimum would appear to be exceptional. It is matter of observation on some western rivers that the low water volume ceases to

decrease and may even increase after vegetation dries up and ceases to draw on the store of ground water. No sufficient study has been given the Upper Mississippi to determine such effects. It is significant that after the low water of December 9, the mean gauge curve shows a rise and an increment throughout the winter such as would indicate an ice cover increasing in thickness and perhaps with little or no diminution in volume.

THE AVAILABLE HEAD.

The gross head between Nashville and Keokuk, as determined by gauge equivalents and as actually existing for characteristic stages, is given in the foregoing tables. The gross heads for the same stages and volumes, dam to Keokuk, dam to power station and wing-dam to power station, are as follows :

NASH. GAUGE	KEOK'K GAUGE	HEIGHT ON DAM	P. S. ABOVE KEOKUK	DAM TO KEOKUK	DAM TO P. S.	WING-DAM TO P. S.
0	-1.26	1.00	5.96	31.26	25.30	14.40
1	1.36	1.33	4.34	29.17	24.83	14.40
2	3.20	1.66	3.50	27.56	24.06	14.40
3	4.93	1.99	2.92	26.16	23.24	14.25
4	6.65	2.37	2.68	24.82	22.14	13.77
5	8.37	2.80	2.40	23.53	21.13	13.33
6	10.07	3.26	2.14	22.29	20.15	12.89
7	11.82	3.77	1.90	21.05	19.15	12.38
8	13.54	4.29	1.67	19.85	18.18	11.89
9	15.26	4.84	1.45	18.68	17.23	11.39
10	16.99	5.40	1.24	17.51	16.27	10.87
11	18.56	6.01	1.10	16.45	15.35	10.44
12	19.67	6.64	1.00	16.07	15.07	10.43

The depth on dam depends on Cornell experiment No. 19, as hereinbefore noted. The elevations at power station are approximate and cannot be certainly determined with the data at command, but are not believed to be seriously in error.

The grossheads above are subject to certain deductions as follows:

1. Dam to Keokuk; lowering on crest of dam to volume drawn by canal, slope in canal and slope in tail-race.

2. Dam to power station; same as above, omitting tail-race.

3. Wing-dam to power station; lower elevation at head of canal than at Nashville, lowering of river due to volume drawn by canal, and the slope in canal.

TABLE OF NET HEADS.

Nash. G.	Volume in canal.	1 Dam and race.	2 Dam to P. S.	3 Wing-dam.	
				Volume.	Head.
0	19.0	27.6	23.6	10.1	10.9
0.1	20.0	27.4	23.6	10.0	11.0
1	20.9	26.6	23.4	9.2	12.0
2	22.2	25.4	23.7	8.8	12.6
3	23.5	24.2	21.9	8.7	12.8
4	24.9	23.0	20.8	8.9	12.5
5	26.2	21.8	19.8	9.1	12.2
6	27.6	20.6	18.8	9.4	11.8
7	29.3	19.4	17.8	9.7	11.4
8	30.9	18.1	16.7	10.1	10.9
9	32.9	16.9	15.7	10.6	10.4
10	35.1	15.7	14.7	11.2	9.9
11	37.0	14.6	13.7	11.5	9.5
12	38.8	14.2	13.4	11.7	9.5

Computations show that the horse-power overruns the assumptions for gross head, except at extreme stages. This can be adjusted by re-computation, except for lowest stages. In No. 1, the low water slope in tail race is excessive. In No. 2, the absolute elevation at the power station is high with respect to low water at Keokuk. In No. 3, the slope

in canal is excessive and a deeper canal is the remedy. Generally, however, the design is shown to be competent, and any change involves additional cost.

RULING CONDITIONS.

The foregoing tabulations are liable to mislead in making a design, as they unduly accentuate the extremes and do not give proper weight to the ruling conditions. The following table gives the fall as deduced from gauge equivalents and the effective heads for characteristic stages.

NASHVILLE GAUGE	KEOKUK GAUGE	VOL. 1000 FEET	CONDITIONS 20-YEAR PERIOD.	1 DAM & RACE		2 DAM & P. S.		3 WING DAM	
				Gross Head	Net Head	Gross	Net	Gross	Net
11.8	19.5	358.0	High Water	16.1	14.2	15.1	13.4	10.4	9.4
8.2	13.9	201.3	Above for 167 days	19.6	17.9	18.1	16.6	11.8	10.9
5.9	9.9	129.9	H. W. mean curve	22.4	20.7	20.3	18.9	12.9	11.8
3.0	4.9	58.2	Mean Stage	26.2	24.2	23.2	21.9	14.2	12.7
1.6	2.5	37.6	Below 2,414 days	28.2	25.9	24.4	23.0	14.4	12.3
1.2	1.8	32.5	L. W. mean curve	28.7	26.2	24.6	23.2	14.4	12.0
0.3	-0.45	22.0	Below for 67 days	30.6	27.2	25.5	23.8	14.4	11.4
0.1	-1.0	20.0	Standard L. W.	31.1	27.4	25.3	23.6	14.4	11.0

The above tabulation indicates the general or normal range in effective head as follows:

1. Dam and tail-race.....18 to 27 feet.
2. Dam without race.....17 to 24 feet.
3. Wing Dam.....11 to 13 feet.

Heads greater or less than the above are to be regarded as exceptional. These erratic heads must be reckoned with, but are not centrolling features in an installation.

It appears that 50,000 effective horse-power may be had with the complete design, 43,000 without the tail-race and 10,000 with wing-dam alone.

EFFICIENCY OF TURBINES.

In the above exhibits, the efficiency of turbines is assumed at 80 per cent of the effective head. This may be true for some particular speed and gate opening, but for generators, a uniform speed is important, and under the large variation in head, the quantities of water used may differ materially from those assumed. If efficicency is obtained at low water, the quantity is ample at other times.

OUTLINE SPECIFICATIONS.

The Water Power Canal is to be located in the river bed adjacent to the east shore and to the east of the boat channel over the rapids and is to begin 2,000 feet below the upper side of Sonora Point and to extend down stream 5 miles to the head of the basin; and said basin is to be ¾ mile long and ¼ mile wide from the shore line at a point ¼ mile north of the outlet of Cheney creek, all as shown on plan.

The prism of said canal is to be 335 feet wide on the bottom at elevation of 10 feet below zero of Nashville gauge and with a slope of 0.8 foot to the head of the basin. The shore side is to be the natural shore face, trimmed to 1½ to 1, except when heavy excavation may be involved. The river face is to be formed by a channeling machine in rock and by a retaining wall, all as shown on drawing.

The river bank of said canal is to consist of an inner masonry wall, a concrete toe-wall, a paved outer slope, and a filling of the waste material, all as shown on drawing. All material for said bank is to

be taken from the canal prism. The bank is to extend to high water limit with dam, or 6 feet above crest, and the filling is to be crowned on top for an additional foot.

The roadway is to be graded along shore from Sonora Point to Cheney Creek to the level of the top of the river bank and surplus material from the prism excavation is to be used for this purpose.

The right of way will cover the canal site and to the east limit of the roadway and generally be limited by the approximate location of the 520 foot contour at elevation 16.25 on Nashville gauge.

The canal entrance will be 350 feet wide and crossed by a light highway bridge in three spans carried on heavy piers and abutments, and the design at this point shall be such as to facilitate the placing of a caisson or coffer-dam in case it should be desired to unwater the canal.

The leading channel from deep water in the river to the canal entrance is to be excavated to canal grade, and is to converge from a width of 800 feet above Sonora Point to 370 feet at entrance.

A bear trap, 100 feet long, is to be located near the outer angle of the basin, the crest of which when down shall be at level of zero of Nashville gauge, and when up at top of wall or 16 feet above said zero. Overflow weirs with flashboards and sluices, shall be constructed if required.

Masonry flumes, carrying the road bridges shall be provided for the outlet of streams that enter the canal, said flumes to be provided with stop logs over which the water tumbles. The backwater basin above any flume will constitute a place of deposit for detritus which can be removed in low water.

The river dam is to be located across the river from the head of the power canal to the guard lock

of the navigation canal at Nashville. It is to be 6,000 feet long and divided into lengths of 1,000 feet with intermediate piers above high water. The two lengths from the canal entrance to Sonora Point are located to the east of the low water channel so the same may be partially constructed as a wing-dam in advance of the main structure. The following three lengths are diagonally across the river and the last length is at right angles to the shore at the guard lock. The crest of dam is to be at elevation 10 feet on Nashville gauge.

The prism of said dam is to be constructed of first-class concrete. The profile is to be of the curved type with rollway, the end of said rollway to be generally thirteen feet below the crest and 24 feet wide on base at said level, all as shown on plan.

The foundation of said dam is to be cut down to solid rock and all joints cleared and filled. It is to be cut down any additional depth required to give a least thickness of three feet of solid concrete under the rollway.

Below said dam for some distance the rock is to be removed to the level of the rollway when above said level, or built up to same and faired off to the rock surface when below said level.

The guard lock of the navigation canal is to be raised to such height as shall be deemed necessary.

The tail-race is to be located from the power station near the outer angle of the basin to the vicinity of the bridge and in the vicinity of the bar shore, the guard bank of said race to be fair with the bank of the basin and to continue same on fair line down stream.

The prism of said race is to have a bottom width of 400 feet, and said bottom to be at elevation 10 feet below zero of Keokuk gauge with grade of 1½ feet to power station.

The guard lock to be formed of the material from excavation, the larger blocks roughly arranged on outer face and top as a protection, said guard-bank to be built above extreme high water.

Progressive construction may be adopted in said tail-race provided the nature of the material be such as to permit of its excavation under water by suitable machinery, and the tail-race with half width may thus be developed in connection with the wing-dam proposition if so desired.

The closing wall of basin is treated as part of the installation hereinafter presented.

THE ESTIMATES.

The estimate is first made up as a whole and is then separated on the basis of a progressive development as follows:

1. Wing-dam without tail-race.
2. Dam without tail-race.
3. Dam with tail-race.

Canal and basin, 5¾ miles long	$ 2,161,233
Rock excavation, 1,245,535 yards at 75 cents	934,152
Toe of slope, concrete, 30,020 yards at $9.00	270,180
Retaining wall, masonry, 180,954 yards at $3.00	542,862
Slope paving, 114,815 square yards at 60 cents	68,889
Leading channel, 2,300 feet long, 334,-200 yards at 75 cents	250,650
Bear trap sluice, 100 feet long	56,000
Bridge and entrance	13,500
Roadway bridges and flumes	5,000
Right of way, 140 acres, more or less	20,000

Dam, 6,160 feet long	281,910
Excavation, 14,430 yards at $1.00	14,430
Concrete, 41,640 yards at $5.00	208,200
Coffer-dam and miscl., $8.00 per foot	49,280
Raising guard-lock	10,000
Damages from back-water	Nominal
Tail-race, 1,415.400 yards at 75 cents	1,061,550
Grand total	$3,504,693

1. Wing-dam without tail-race, for 10,000 effective horse-power.

It is proposed to construct the front face of the dam for two lengths, or 2,060 feet, to elevation 5 feet on Nashville gauge so as to serve as a wing-dam, at an estimated cost of $25,000.

The estimated cost of canal with leading channel complete and including wing-dam would therefore be	$ 2,186,233
Per horse-power	218.62

2. Dam without tail-race, for 43.000 effective horse-power.

Cost of canal as above	$ 2,186,233
Cost of dam, additional	256,910
Total	$2,443,143
Per horse-power	56.82

3. Dam with tail-race, for 50,000 effective horse-power.

Tail race, additional to above	$ 1,061,550
Total	3,504,693
Per horse-power	70.09
The extra 7,000 horse-power costs per horse-power (without addition installation	151.65

EXPLANATION.

In the foregoing estimate the unit prices for masonry and concrete assume that rock has been once paid for in excavation. The price of excavation also covers placing of material in embankments, roadway and waste pile. A lineal foot price is added for coffer-dams in connection with main dam and in toe-wall for embankment. No closing wall at lower end of basin is estimated and this is to be included in the installation.

MODIFICATION OF ESTIMATE.

It is to be noted that $1,184,182, or 55 per cent of the estimate for canal, basin and leading channel, is for excavation. This channel is as small as should be made and to reduce this item would require a material change in location and an encroachment in the river which has not seemed permissible. If the leading channel can be developed progressively and with economy by suitable machinery, then some 40 per cent of this portion of the excavation can be omitted until the main dam is undertaken, with a temporary saving of $100,000.

The omission of the slope paving would save about $69,000 and the substitution of a timber-crib for the toe-wall, about $150,000, and a reduction in height of bank by four feet about $81,000, a total of $300,000, or $400,000 including the excavation hereinbefore noted. The estimate for wing-dam proposition would then be $1,786,233.

The remaining excavation and the raising of the bank, at additional cost, would be required whenever the project developed beyond the wing-dam stage. The saving of $219,000 by omitting the toe-wall and paving is doubtful economy.

No project for constructing the main canal bank and making the same tight and safe has suggested itself as less costly in view of the excavated material to be disposed of.

THE INSTALLATION.

It is taken for granted that the power will, in large part, be utilized at a distance from the power station and that it will be electrically transmitted. Electrical transmission for power purposes, especially to long distances, is largely the outgrowth of the alternating current system. The number of alternations is a determining quantity as it fixes the speed of all motors, except as converters may change the alternating current to a direct current for special use as in railway service. It will therefore be seen that a uniform speed in the generators is essential and that the number of alternations is practically fixed for the entire development.

To provide a turbine installation that will give such uniform speed under wide variations in head and that shall, at the same time, be available for the higher heads due to the progressive development herein contemplated, is a matter for very serious consideration, and its best solution may involve a special design. For preliminary considerations and purposes of estimate, the standard types of commercial wheels have been relied on.

There are several makes of wheels that give excellent results through a considerable range of gate opening and the particular adaptation to the arrangement that may be imposed will govern the choice. To make the same wheels do service for the low head conditions, as with wing-dam, and later under high head conditions, it will be necessary to speed up by belting and later change to a different

speed ratio or connect directly to the turbine shaft. By this treatment the intermediate connections only require to be changed for the high level conditions with the Nashville dam.

The generator is, however, a fixed quantity that may use two or more turbine units under the low head condition and require but one under the high head conditions.

These several considerations were developed early in July and these conditions are so much more arduous than those encountered by the recent great installations that special advice was sought. This has occasioned over a month's delay, but without radically changing the proposed treatment.

POWER UNITS.

The turbine unit is to consist of eight standard turbines, 43 to 45 inches in diameter, coupled on a horizontal shaft and capable of delivering 1,125 effective horse-power under the minimum head, for the wing-dam stage of development. Two of these units are to be belted to one 1,500 kilowatt generator.

Each of these turbine units will develop twice the minimum horse-power (2,250) under the high head conditions and then a single generator can be directly connected to each unit. The turbine speed is taken at 180 revolutions with 23 feet head, the range in head being from 18 to 27 feet.

POWER STATION.

The station is to have eleven bays or galleries for ten turbine units. Each gallery is to consist of a fore-bay and a tail-bay beneath, the floor of the fore-bay to carry the turbines which are to discharge by draft tubes through same. The tail-bay is to discharge by two culverts under the generator room into the tail-race below. The floor of the fore-bay is to be at such elevation as will give the proper section

for feeding the turbines, and the floor of the generator room is to be at such elevation as will permit the generator to be connected directly to the turbine shaft. The bottom of the tail-bay and of the culverts are to be at such elevations as will give the proper area for the discharge from the turbines. The walls between bays and the walls of generator room are to be sufficient to stand the pressure under the most adverse conditions. The sketch (sheet 3) shows the proposed arrangement and the proportions, subject to amendment in a final design, but sufficiently close for an approximate estimate.

The power-station for the high level conditions differs only in respect to distance between centers of bays, which is to be 40 feet in place of 45 feet; and in height of floors which are to be at nine feet greater elevation in fore-bay and in generator room. This enables the bottom of the tail-bay and culverts to be raised to such elevation as will leave the proper section below the tail-race level. This arrangement gives a higher elevation to the generator room which is very desirable, and is more economical than the low level station which must be adapted to wider extremes. The high level station is to have 13 bays.

The fore and back walls of the generator room are to be carried up in brick work and the roofing is to be of metal or metal and slate. Suitable offsets are to be left for an overhead traveling crane.

THE ESTIMATE FOR POWER STATION

With 11 bays, adapted to both the low level and high level plan is as follows:

Excavation, 98,000 yards at 75 cents	$	73,500
Rubble and concrete, 54,000 yards at $3.50		189,000
House		59,500
Closing wall		20,000
Total, Station No. 1	$	342,000

The estimate for the high level station with 13 bays, is as follows :

Excavation, 70,000 yards at 75 cents	$ 52,500
Rubble and concrete, 50,000 yards at $3.50	175,000
House	62,500
Total, Station No. 2	$ 290,000

The closing wall, estimated as part of Station No. 1, can be so designed as to save $10,000 in the above estimate for Station No. 2, when the same shall be undertaken.

Station No. 3, when required, will be located differently and will not be subject to any deduction.

Turbine estimate. The cost of four pair of 43-inch turbines on horizontal shaft with draft tubes, governors and coupling for direct connection to generator and all appurtenances, delivered f. o. b. Keokuk, is given by the builders at $25.000. The diameter may vary from above for other styles of turbines of same power.

Racks, a set of gates that can be applied to any bay and miscellaneous accessories, and the putting of all in place, is taken at $2,000 per bay or power unit.

It is assumed that the entire power is to be applied to generators and for the low level development, two power units must be connected to one generator and speeded to 180 revolutions by means of pulleys and belting. The estimate is taken at $2,000 per power unit.

Exciter units in duplicate must be provided, each of which will require 240 horse-power capacity and be sufficient for five generators. Each unit is to be made up of three 33 to 35 inch turbines on horizontal shaft, turning at 230 revolutions under 23 feet head and speeded up by pulleys for the low level development. The estimate for the two units in place and

for the bay furnishings, is taken at $18,000. The exciters are usually estimated for direct connection and the mountings, pulleys and belting are taken the same as for other bays, or $2,000.

The power estimate will be as follows:

10 power units at $29,000	$	290,000
2 exciter units		20,000
Total, low level	$	310,000

When this station is changed to a high level station, each power unit will be doubled, and all generators and exciters will be direct connected. It is assumed that the salvage in the intermediates will rearrange the generators and exciters, so that the power estimate will remain at $310,000.

The high level station (No. 2) will be as follows:

12 power units at $27,000	$	324,000
2 exciter units		18,000
Total	$	342,000

Station No. 3, when required, will be the same as Station No. 2 above.

Recapitulation. The cost of station and power installation is recapitulated as follows:

Station No. 1, estimate	$	342,000
Power units, 10		310,000
Total	$	652,000
Station No. 1, high level, for double the power, same as above, or	$	652,000
Station No. 2, estimate	$	280,000
Power units, 12		342,000
Total		622,000
Station No. 3		632,000

Results. The rating hereinbefore has been based on the turbine shaft. A 1,500 kilowatt generator is the equivalent of 2,000 horse-power and the efficiency may be taken at 95 per cent, or it will require about 2,100 horse-power to drive it by direct connection.

The efficiency of the intermediate pulleys and belting may be taken at 96 per cent, or it will require about 2,200 horse-power to drive the generator through these connections. The generators are capable of carrying 25 per cent of overload, or working up to 2,500 horse-power, and this latitude is provided to cover ordinary variations in load.

It will be perceived, therefore, that Station No. 1, low level, has a margin of power and that four generators may work up to the limit in extreme low water. This margin is a proper safety factor, and the station is rated as before at 10,000 horse-power.

Under high level conditions this station will be somewhat more reliable for double the power and will be rated at 20,000 horse-power.

Station No. 2 may be rated at 24,000 horse-power.

Station No. 1 and No. 2 may together be rated at 44,000 horse-power, and will cover the 43,000 hereinbefore assigned to the high level conditions without tail-race. This installation should also be equal to 50,000 horse-power with tail-race.

Station No. 3 is to meet the variable demand when the capacity of No. 1 and No. 2 is exceeded. The cost per horse-power rating is as follows:

No. 1, 10,000 horse-power, low level	$ 65.20
No. 1, 20,000 horse-power, high level	32.60
No. 2, 24,000 horse-power, high level	25.92
No. 1 and No. 2, 43,000 horse-power	29.63
No. 1 and No. 2, 50,000 horse-power	25.48
No. 1, No. 2 and No. 3, 50,000 horse-power	38.12

The three stations together will have a normal capacity of over 70,000 horse-power and a range considerably above, which will provide for variations in demand on the basis of a constant power of 50,000.

THE COST PER HORSE-POWER.

The horse-power as herein computed is the effective power, taken at the point where applied to the generator.

The farmer can only know the cost of producing a bushel of grain after the crop is harvested and threshed, and the profit after marketing the same. The railway auditor can only figure the cost per ton-mile and the profit after the season's operations. It is much the same in water-power development.

With a miscellaneous market, a portion of the demand will be for constant power, a portion for constant power for a certain number of hours on every working day and another portion will be variable for a part of each day. This matter is presented at length in the Supplement. Such variable demand requires a large storage capacity by pond or reservoir, or a large surplus flow in the stream, and a plant sufficient for the maximum demand, in order to utilize most fully the available horse-power hours.

In the following estimate it is assumed that an installation 50 per cent in excess of the constant rating will enable five-sixths of the horse-power hours to be sold.

The cost of producing the power is taken as the fixed charge; as, interest and taxes, maintenance and supplies, renewals, service and management.

1. Interest and taxes; 5 per cent on cost.

2. Maintenance and supplies; 2 per cent on power installation and appurtenances, and ½ of 1 per cent on permanent work.

3. Renewals; 3.23 per cent on power installation, etc. (Annuity; 4 per cent and 20 years.)

4. Service and management; experience alone will determine. The service will be largely incidental to that of the electrical installation. Take ¼ of 1 per cent of permanent work, 1 per cent of power installation and one-third of combined service at power station. This combined service is taken at $21,000 for the 10 unit station and $24,000 for the 12 unit station, or $7,000 and $8,000 respectively for the power installations.

The aggregate will be as follows:

Permanent work ..... 5.75 per cent
Power installation ..... 11.23 per cent
Arbitrary, $7,000 and $8,000 for station as above.

It will be convenient to consider the several cases in the reverse order of development.

1. Canal, dam and tail-race and three stations.

Rating, 50,000 horse-power. Installation, 71,000 horse-power.

Horse-power hours, salable, 360,000,000.

Yearly charge	$ 388,586
Permanent work, $4,416,693 at 5.75 per cent	253,960
Power installation, $994,000 at 11.23 per cent	111,626
Arbitrary	23,000
Cents per horse-power hour	0.1079

2. Canal, dam and three stations.

Rating, 43,000 horse-power. Installation, 71,000 horse-power.

Horse-power hours, salable, 310,000,000.

Yearly charge	$ 327,547
Permanent work, $3,355,143 at 5.75 per cent	192,921
Power installation, $994,000 at 11.23 per cent	111,626
Arbitrary	23,000
Cents per horse-power hour	0.1057

3. Canal, dam and Stations No. 1 and No. 2.
Rating, 43,000 horse-power. Installation, 46,000 horse-power.

Horse-power hours, salable, 222,000,000.

Yearly charge	$ 264,466
Permanent work, $3,065,143 at 5.75 per cent	176,246
Power installation, 652,000 at 11.23 per cent	73,220
Arbitrary	15,000
Cents per horse-power hour	0.1196

4. Canal, dam and Station No. 2.
Rating 24,000 horse-power. Installation 25,200 horse-power.

Horse-power hours, salable, 121,000,000.

Yearly charge	202,987
Permanent work, $2,723,143 at 5.75 per cent	156,581
Power installation, $342,000 at 11.23 per cent	38,406
Arbitrary	8,000
Cents per horse-power hour	0.1677

5. Canal, dam and Station No. 1.

Rating 20,000 horse-power. Installation, 21,000 horse-power.

Horse-power hours, salable, 101,000,000.

Yearly charge	$ 201,959
Permanent work, $2,785,143 at 5.75 per cent	160,146
Power installation, $310,000 at 11.23 per cent	34,813
Arbitrary	7,000
Cents per horse-power hour	0.2000

6. Canal, wing-dam and Station No. 1. (Low level.)

Rating, 10,000 horse-power. Installation, 10,500–11,000 horse-power.

Horse-power hours, salable, 50,000,000.

Yearly charge	$ 187,186
Permanent work, $2,528,233 at 5.75 per cent	145,373
Power installation, $310,000 at 11.23 per cent	34,813
Arbitrary	7,000
Cents per horse-power hour	0.3744

6A. Modified canal, wing-dam and Station No. 1. (Low level); power, same as (6) above.

Reduction in permanent work, $400,000 at 5.75 per cent, or $23,000 less on yearly charge.

Yearly charge	$164,186
Cents per horse-power hour	0.3284

It may be legitimate to assume a larger proportion for local use and a less proportion of variable power in the initial or minor installations and this assumption would increase the use and diminish the

unit cost, as above given for such installation. Again, the larger installation approach more habitually the water supply limit. A large excess, or range, except for a very limited period, is not permissible in the low level scheme without material modification in low water canal prism.

In assigning limits to the station capacity in the foregoing estimates, each power unit is taken at 2,100 horse-power or that required to deliver 1,500 kilowatts, or 2,000 horse-power from the generator unit. The intermediates in the low level scheme will require an additional 100 horse-power. The generators have still an overload capacity for variations in ordinary working conditions, not considered in fixing the normal limits.

The foregoing estimates give the cost of the power at the turbine shaft, or at the shaft of the generator where intermediates are used, and for the time when power is used to the extent assumed. A less use of power will, of course, raise the cost per unit, and *vice versa*. The cost per year for any use can be estimated by the number of working hours.

ELECTRICAL INSTALLATION AND TRANSMISSION.

All power is assumed to be converted into electricity by generators and transmitted to substations, there to be distributed to actual users. It is impracticable at this time to forecast the actual conditions of use, but certain approximate estimates can be made which will be a criterion for judgment.

The efficiency of the several elements involved in generating and transmitting electrical energy under commercial conditions may be taken as follows:

Generators 95
Step-up transformers 97
Line 94
Step-down transformers 97

The line loss is taken uniformly at 6 per cent with the voltage at 1,000 volts for each line of transmission.

The generator unit is taken at 1,500 kilowatts (equivalent to 2,000 horsepower.) The estimate for "one three-phase revolving field 40 pole 1,500 K. W. 180 r. p. m., 2,300 volt generator provided with base, shaft and two bearings for direct connections to water wheel, same complete with rheostat and generator panel, say $14,000.00." Exciter in duplicate for five generators, "one M. P. 6 pole, 160 kilowatt 230 r. p. m., 125 volt exciter without shaft, base or bearings, complete with rheostat, will cost approximately	$ 3,200.00
The cost per generator is	1,280.00
The freight, cartage and installation of above is estimated at	1,720.00
The cost of one unit in place may therefore be taken at	17,000.00
"Three water-cooled 60 cycle 500 K. W. 2,300 volt primary, 25,000 to 40,000 volt secondary step-up transformers with high tension panel for same, say	7,300.00
For sub-station, three 500 kilowatt 60 cycle air blast transformers to step-down from line voltage to 2,300 volts for local distribution, same complete with one high and one low tension panel, say	8,000.00

The freight, cartage and installation of above may be taken at	1,700.00
The cost in place for one generator unit may therefore be taken at	16,000.00
Sub-station building per unit	2,000.00
The copper required to transmit one unit under conditions stated, 2,500 pounds per mile in three No. 3 wires; price 19 cents per pound or 20 cents in place	500.00
Poles, cross-arms, insulators, etc., in place, per mile, $300.00 to	400.00
Six lightning arresters, per unit, $600.00 to	1,500.00

With the above data, the following conditions may be estimated for 5 units, or 7,500 kilowatts :

1. Direct transmission within limits of 2 to 3 miles.

5 station units at $17,000		$ 85,000.00
30,000 lbs. copper at 20 cents	$ 6,000	
15 miles pole line at $340	5,100	
Lightning arresters, etc	3,900	15,000.00
Total installation		$100,000.00
Yearly charge, 12 per cent	$ 12,000	
Arbitrary	8,000	$20,000.00
Per horse-power hour (50,000,000 behind generator)		.040c

The efficiency is .95 x .94 or 89.3 per cent; or it will take 1.12 horse-power behind the generator to produce one horse-power at point of delivery. The cost delivered will therefore be the above figure, plus the cost at turbine shaft, increased by 12 per cent.

The cost will vary endlessly according to pole lines, as there will be 15 wires, each for 500 kilowatts, and the delivery can be in this unit or multiples thereof.

2. Ten-mile transmission to sub-station.

The generators would be wound for 10,000 volts and upward for direct transmission and a step-down transformer used at distributing station. The cost for changing the voltage is taken at half that for the estimate (3) following:

Five station units at $17,000		$ 85,000.00
Transformers		40,000.00
Copper, 125,000 lbs. at 20 cents	$ 25,000.00	
Ten miles pole line	4,000.00	
Lightning arresters, etc.	6,000.00	35,000.00
Substation		10,000.00
Total installation		$170,000.00
Yearly charge, 12 per cent	$ 20,400.00	
Arbitrary	8,000.00	$28,400.00
Per horse-power hour (50,000,000 behind generator		.0568c

Efficiency, .95 x .94 x .97 or 86.6 per cent; or, it will take 1.154 horse-power behind the generator to produce one horse-power ready for delivery from sub-station.

3. Forty-mile transmission to sub-station.

A step-up transformer at generating station, a step-down transformer at distributing station and transmission at 40,000 volts.

Five station units at $17,000		$ 85,000.00
Transformers 5 at $16,000		80,000.00
500,000 lbs. copper at 20 cts.	$ 100,000.00	
40 miles pole line at $400	16,000.00	
Lightning arresters, etc	9,000.00	125,000.00
Sub-station		10,000.00
Total installation		$300,000.00
Yearly charge, 12 per cent	$ 36,000.00	
Arbitrary	8,000.00	$44,000.00
Per horse-power hour (50,000,000 behind generator)		.088c

The efficiency, .95 x .97 x 94 x .97, or 84 per cent; or, it will take 1.19 horse-power behind the generator to produce one horse-power ready for delivery from sub-station.

The Local Distribution. Motors of good size should give an efficiency of 90 per cent. Local line losses will vary greatly, but it should be practicable to obtain an efficiency of 85 per cent between the sub-station and the motor shaft. A 25 horse-power motor will cost about $750, or $30 per horse-power; and a 300 horse-power motor will cost about $4,500, or $15.00 per horse-power.

The direct application of power through motors of convenient size and wiring is very efficient and economical as compared with the ordinary methods of power application in shops.

The efficiency between the turbine shaft (behind the generator) and the delivery from the motor, may be taken for the three cases as follows:

	PER CENT.	HORSE POWER.
1. Direct transmission	76-80	1.28
2. Ten-mile transmission	73-74	1.36
3. Forty-mile transmission	71-72	1.40

The approximate horse-power behind the generator to deliver one horse-power from the motor is given in the second column.

Comparison with steam power is better represented by the preceding results:

	PER CENT.	HORSE POWER.
1. Direct transmission	89.3	1.12
2. Ten-mile transmission	86.6	1.154
3. Forty-mile transmission	84.0	1.19

One or more wires can be run direct wherever steam power exceeds 500 kilowatts.

Lighting and street car work are normally from central stations. Small powers can be advantageously furnished from central station steam plants.

The proper comparison is with direct wiring for large units and sub-station delivery for certain service and for small powers.

DISCUSSION.

For the present purpose, the average of the three cases under "Electrical Installation," may be taken for the working conditions.

TRANSMISSION.	INVESTMENT.	YEARLY CHARGE.	CENTS H.P HOUR	PER CENT EFFICIENCY	HORSE POWER
1. Local	$100,000	$ 20,000	0.040	89.3	1.12
2. 10-mile	170,000	28,400	0.057	86.6	1.154
3. 40-mile	300,000	44,000	0.088	84.0	1.19
15 units	$570,000	$ 92,400	0.0616	86.6	1.155

Horse-power hours, 150,000,000 behind generator. The cost per horse-power is also behind generator and can be converted by factor in last column.

The above may be applied to the several conditions under the head, "The cost per horse-power."

Case 6: wing-dam; 5 units.

Investment	$ 2,838,233	
One-third above	190,000	$3,028,233
Yearly charge	$ 187,186	
One-third above	30,800	$ 217,986
Per horse-power hour, 0.3744-0.0616		0.436c
Per horse-power hour delivered (factor, 155)		0.504c
Per horse-power year, 5,000 hours (average)		$ 25.20

In comparison with efficient steam power:

	HOURS.	CENTS HOUR.	YEAR.	CENTS HOUR.	YEAR.
Constant	8,640	0.6	$ 51.84	0.378	$ 32.66
Factory	3,000	0.8	24.00	0.504	15.12
Variable	(?)	1.0	(?)	0.630	(?)

Case 6A: Modified wing dam; 5 units.

Investment, $2,628,233; yearly charge, $194,986.

Horse-power hour, 0.39 cents; delivered 0.45 cents.

Horse-power year, 5,000 hours (average) $22.50.

Case 5: Dam; 10 units.

Investment, $3,475,143; yearly charge, $263,559.

Horse-power hour, 0.2616 cents; delivered, 0.302 cents.

Horse-power year, 5,000 hours, $15.10.

Case 4: Dam and station No. 2; 12 units.

Investment, $3,521,143; yearly charge, $276,907.

Horse-power hour, 0.2293 cents; delivered, 0.2648 cents.

Horse-power year, 5,000 hours, $13.24.

The foregoing cases cover the wing-dam (6A) as an independent proposition, the same (6) as the initial stage of a progressive development; and the same station (5) for the high level, or second stage of development; also high level Station No. 2 as an initial development with dam. These may be recapitulated as follows:

	INVESTMENT.	H. P. YEAR.
6A	$ 2,628,233	$22.50
6	3,028,233	25.20
5	3,475,143	15.10
4	3,521,143	13.24

The query at once suggests itself: Why not start with the high level proposition? Even with a

6-unit station (4) the investment would be practically the same as *Case 6* and the cost less per horse-power year.

It appears that the wing-dam proposition (6A) involves a large investment in proportion to the power produced and that the cost per unit is high and leaves a doubtful margin for profit, considering the price at which it must be sold to replace existing steam plants. The case would be better for new industries and especially for those located at the power site, but the main inducement for such new industries will be power that can be sold much cheaper than steam power can be produced.

A wider encroachment on the river bed than has seemed permissible in this project would cheapen the canal, but this would probably be offset by the cost of a deeper prism, such as is required for the best efficiency at low water, considering the project as a wing-dam proposition alone. Again, the cost of installation is high in proportion to the output, so no large economy for a different treatment is to be expected.

The same remarks will apply with greater force to the wing-dam stage of the progressive development (Case 6), as this carries an extra capital charge which is not utilized until the succeeding stage (Case 5), where the cost per unit is reduced by some 40 per cent or within safe limits. This development, if justified, will find its warrant in an earlier sale of power than might otherwise be practicable, but it must anticipate a larger market at an early day and that the dam will not be indefinitely deferred.

The initial development (Case 4) with the construction of the dam and high level station is most satisfactory and the cost per unit is well within commercial limits. The results on further development are as follows :

Case 3: Dam, 22 units.

Investment, $4,553,143; yearly charge $399,986.

Horse-power hour, 0.1806 cents; delivered 0.2086 cents.

Horse-power year, 5,000 hours, $10.43.

Case 2: Dam 34 units.

Investment, $5,541,143; yearly charge, $436,987.

Horse-power hour, 0.1673 cents; delivered, 0.1932 cents.

Horse-power year, 5,000 hours, $9.66.

Case 1: Dam and tail-race; 34 units.

Investment, $6,602,693; yearly charge, $498,026.

Horse-power hour, 0.1695; delivered, 0.1958.

Horse-power year, 5,000 hours, $9.79.

The apparent increase per unit in Case 1 over Case 2 is due to cost of tail-race. The extension of the basin as suggested in Supplement will offset this increase and reduce all estimates slightly. If Station No. 1 is built as a high level station at the outset, the estimate will also be reduced slightly. The chief utility of the tail-race is to increase the amount of horse-power and the efficiency of the installation.

It will be noted that after one-third the horse-power is installed on the high level plan, the cost per unit is not greatly reduced by addition installation. This is particularly true for the second half of the installation. This is due in part to progressive development and also to the fact that installation is an increasing proportion of the total investment and that the cost of same varies with the output.

After the initial installation of about one-third the total units to be ultimately provided, it will be practicable to add additional units in groups, (of say, 5) so that this proportion of the investment can be made as the prospective demand shall warrant.

That portion of the investment and the yearly charge which varies directly (this is not exactly true) with the output capacity, for high level conditions, is as follows:

	INVESTMENT.	YEARLY CHARGE.
Power station	$ 24,000	$1,380
Turbines, exciters, etc	28,500	3,870
Electrical installation	38,000	6,160
For one unit	$ 90,500	$11,410

This corresponds normally to 10,000,000 horse-power hours behind generator and represents a cost of $6.59 per horse-power year delivered. This is decreased slightly for the large installations in foregoing tabulations. The further charge for the primary work is a fixed quantity to be divided by the number of units of power installed.

It will be useful to consider the project of a dam at the foot of the rapids (see Supplement). The cost of the primary work will be taken at $2,500,000 and the installation as above, and the constant power as 60,000.

Initial Development: 15 units.

Investment, $3,857,500; yearly charge, $314,900.
Horse-power hours, 151,000,000 behind generators.
Per horse-power hour, 0.209 cents; delivered, 0.241 cents.
Horse-power year, 5,000 hours, $12.05.

Ultimate Installation: 40 units.

Investment, $6,120,000; yearly charge, $600,150.
Horse-power hours, 432,000,000 behind generators.
Per horse-power hour, 0.139 cents; delivered, 0.160 cents.
Horse-power year, 5,000 hours, $8.00.

A certain portion of the investment would be for a lock and other navigation works and this would lessen the yearly charge. The works would also be relieved of certain charges incident to a canal. The output would also be increased, as loss of head by canal is avoided.

It will probably be found advantageous to make the dam three feet higher than the one projected for Nashville, thus producing a constant power of 60,000. Construction cost and damages would be increased, but these would probably be more than met by saving in installation. Units of 2,000 kilowatts would probably be economical and conditions bettered in other respects. The above estimate may therefore be taken for this condition, though no close estimate can be made for such a project without special data.

The alternative project is suggestive as disclosing possibilities. The study, however, has proceeded on the basis of a canal and wing-dam, expanding into a dam at the head of the navigation canal, as being consistent with the permit, and as involving no radical change in existing federal property. In any event, such study has been expedient in order to develop the subject matter and clear the way.

GENERAL CONSIDERATIONS.

This study confirms previous study of large enterprises — that the most comprehensive and boldest treatment is most effective and economical. Nature has fashioned the situation on so large a scale and so completely, as to leave little opportunity for partial development. No island, no chute, no configuration of river bed or trick of foreshore, divides the problem and invites a limited treatment complete in itself and that can be merged into a larger solution.

Treated broadly, however, and on the basis of a considerable initiation installation, it is feasible to produce at moderate cost one of the greatest of water-power developments. It is probable that final data and study can mature a project that will not cost over $35,000 per horse-power for primary work, or about $2.00 per year, and about the same for plant, or $5.00 per year; say a total of $7.00 per horse-power year of 5,000 hours delivered to large consumers and to sub-stations anywhere within a radius of forty to fifty miles, at the time of full development and use. On the basis of one-third development the equivalent charge would be $11.00.

A dam at the foot of the rapids is not only most effective from the water power standpoint, but has positive advantages for navigation, over the dam at Nashville. A single lock will be less costly to maintain and operate than the present canal and it will facilitate navigation. The pool above the dam will constitute a radical improvement of the stream for navigation for thirty miles or more, one step in such improvement as the future may, and should demand. Present projects for river improvement will be cheap-

ened. The project properly worked out, is not one for any intrinsic objection; water-power development is to be encouraged by sound public policy and the contribution to navigation, present and future, would well justify the Federal Government in providing for the navigation features, if no more.

The important function of the pond in conserving the low water volume for the daily variation in demand in an ultimate development, is a reason for the dam, in addition to the head of water and navigation.

The remarkable results which electricians are now prepared to guarantee make feasible the transmission of power to long distances. The cheapness with which power can be produced by a proper project would probably justify commercial transmission to a distance of one hundred miles.

In the Appendix is given the population within a radius of forty miles. In the early development a power line would probably be taken down the Missouri shore to Quincy and Hannibal, supplying towns enroute directly or by short side lines. A similar line can be carried up the Iowa shore to Fort Madison and Burlington and extended to Galesburg by Monmouth. A third line could go eastward by a number of considerable towns to Pekin and Peoria. To supply the local demand within the radius of a few miles is comparatively simple.

The direct use of power from the wheel can be made for some purposes and a location at the power site is then advantageous. Plants using a large number of small units or long trains of shafting, are costly and wasteful, and can be better served by wiring and individual motors and these can be located anywhere within the limits of transmission at ordin-

ary voltage. As a general proposition power will be cheapest in the locality where produced and large users will be disposed to establish new industries in the vicinity of the power site.

There is no reason why cheap water-power, such as can be had by proper treatment of the Des Moines Rapids, should not produce a great industrial development. Keokuk is on a navigable stream and is well served by railway and can readily grow to a trunk line point; it is in the productive heart of the great interior and at the middle of the corn belt; timber from the north, cotton and timber from the south and all the products of a great agricultural region can assemble here; it is in the center of a great home market and the climate is good. It can mill grain as well as Minneapolis and St. Louis, make whiskey as well as Peoria, make paper as well as on Rock River, spin cotton with New England, and do a thousand things better than at Niagara or Messena, which are less favorable to market.

If the statement be accepted that water power towns contain from 3 to 5 people for each developed horse-power and that the wealth of such a community is a thousand per capita, then the public policy of such enterprises becomes profoundly significant and they should excite the solicitude of the state. From this view point the question is one of cheap power rather than large dividends from the direct investment.

Keokuk can rely more safely than some other points that have attracted large capital, on the theory that the power produced will make its own market.

CONCLUSIONS.

1. The wing-dam project, as a separate enterprise, does not appear to be justified as a commercial enterprise from a dividend standpoint. The cost per horse-power unit is too high for distribution in competition with steam and leave a profit to the investor. For direct application of power to industries at the power site it makes a somewhat better showing.

2. The wing-dam project as the initial stage of a progressive development, is a doubtful commercial proposition. It must be followed without delay by the high level development, and then the power arrangements are not the best and must be rearranged with some loss.

3. The dam and canal project gives most excellent results and will be commercially justified when the prospective demand is one-third the ultimate development, say 11 units, or 20,000,000 horse-power hours delivered to power consumers. This will give 6 per cent over the yearly charge and leave a fair margin against steam competition.

4. The ideal project is by dam at foot of rapids. Data for close estimate is not available and authority must be secured. It will probably be commercially justified with a prospective demand of one-fourth the ultimate development, say 18,000,000 horse-power hours to consumers.

THE INVESTIGATION.

The investigation, especially of the physical conditions, has been extremely laborious and tedious, as it involved a knowledge and consideration of the history of the river for the past twenty years. The question of design has also been perplexing, owing to the range in fluctuation and variation in same between the head and the foot of the rapids.

Mr. Janus A. Seddon was employed to make the special investigation in regard to gauge relations, discharge curves and flow levels. Mr. Seddon has been engaged in similar work for the Mississippi River Commission and the Missouri River Commission for some 15 years, and is the leading expert in such matters. His determinations have been taken with great confidence as the best to be had in the absence of direct observations.

Mr. Edgar Williams, an engineer of long experience, has worked up the detail of the gauge curves at Nashville and Keokuk, made the computations and done the drawing.

Mr. James W. Johnson, of the General Electric Company, by permission of the western office, Mr. B. E. Sunny, western manager, has furnished important data and estimates in respect to installation and the transmission of power. This enables a presentation of the latest results and this assistance has been most valuable.

The following special data have been used in determining results :

Gauge Records: Hannibal, Warsaw, Keokuk, Nashville, Burlington—Mississippi River Commission and United States Weather Bureau, Special at Nashville by Major C. McD. Townsend, Corps of Engineers, U. S. A.

Measured Discharges: Hannibal, Burlington—Published record by Mississippi River Commission; Special at Burlington by M. Meigs, U. S. Civil Engr.

Charts: Published charts of Mississippi River Commission; also a tracing on a large scale furnished for this special study from the office of the Commission.

Miscellaneous: High and low water elevations and distances, Rock Island to St. Louis, and miscellaneous information by M. Meigs, United States Civil Engi-

neer. Data for profile of water surface of east shore at uniform stage taken especially for this study by J. Ross Robertson, City Engineer of Keokuk. Basin areas, from Warren's Bridging the Mississippi.

Unit Prices: Excavation, rubble, and concrete masonry, on cost of similar work on the Chicago Sanitary and Ship Canal and the Soulanges Canal, and on quotation for Portland cement, f. o. b. Keokuk, supposing rock to be as good as at Chicago. The experience had might reduce these prices in dull times but they are not higher than present times and conditions at Keokuk appear to warrant. The prices for turbine plant were furnished by Mr. A. F. Sparks, General Manager of the James Leffal's Company, and the data for electrical installation by Mr. James W. Johnson of the General Electric Company. Some unimportant items have been assumed.

The Estimates add nothing for contingencies and engineering, and are assumed to cover. Final data and study, it is presumed, will show a proper margin for these items. Meantime, the figures are as close as the information justifies.

MAPS AND DIAGRAMS.

In three sheets:

1. Map on scale of 1–10,000 showing rapids from above Nashville to bridge, with contours of shores and bottom and elevations of bottom along east shore and of water surface; also location of canal, basin, dam, tail-race and right of way.

2. Profile and sections of dam, canal, basin and tail-race, with low water lines; back-water profile; general profile with flow level; mean gauge curves at Nashville and Keokuk with discharge equivalent.

3. Sketch showing general lay out of the power station and installation on low level plan. The high level plan differs only as set forth in text.

APPENDED MATTERS.

Supplement:

1. Modification of Basin.
2. Dam at Middle Lock.
3. Dam at Lower Chain.
4. Possible Horse-Power.
5. The Pond.
6. Value of Power.

Appendices:

1. Table of Discharge, Nashville.
2. Discharge Curves.
3. Flood Expectation.
4. Discharge over Dam.
5. Population.

Chicago, August, 1901.

SUPPLEMENT.

(To Preliminary Report—Water Power of the Des Moines Rapids.)

The Supplement treats of modifications of project, alternative schemes, and sundry topics of collateral interest.

1—MODIFICATION OF BASIN.

Extend basin ¼ mile on land side and ⅓ mile on river side, as suggested in main report.

The saving in tail-race will be as follows:

Excavation, 356,300 yards at 75 cents	$	267,225

The additional cost will be as follows:

Masonry, 13,657 yards at $3.00	$	40,971
Toe-wall, concrete, 1,760 yards at $9.00		15,840
Paving 9,000 square yards at 60 cents		5,400
Filling, 71,755 yards		
Total, 1,760	$	62,211
Saving in completed scheme	$	205,014

The additional low water fall for this distance will be nominal.

It is evident that the further down stream the basin is carried the less the aggregate cost including tail-race.

At about ¾ mile above bridge will be realized the largest increment to the low water fall without the tail-race.

2—DAM AT MIDDLE LOCK.

A trial estimate for a dam 6,160 feet long, including piers and abutments, across the river at or near the Middle Lock is made for comparison. This scheme includes raising guard-lock as before and the canal bank between the Upper and Middle Lock, with canal and basin from east end of dam, as herein before designated below the proposed location. The crest of the dam is to be at same elevation as for Nashville and the height 24 feet above lower end of rollway. Prices are based on borrowed material.

Dam, 6,160 feet		$ 533,926
Excavation, 23,680 yards at $1.00	$ 23,680	
Concrete, 83,812 yards at $5.50	460,966	
Coffer-dam and miscellaneous at $8.00 per foot	49,280	
Navigation canal		$ 210,000
Raising guard bank, 400,000 yards at 50 cents	200,000	
Raising guard lock, as before	10,000	
Power canal, 8,000 feet		$ 594,880
Masonry, 62,080 yards at $3.75	$ 232,800	
Toe-wall, concrete, 8,000 yards at $9.75	78,000	
Paving, 41,000 square yards at $1.00	41,000	
Filling, 326,160 yards at 50 cents	163,080	
Miscellaneous	80,000	
Grand total		$ 1,338,806
Tail-race		$ 748,875
Additional excavation, 790,000 yards at 75 cents	$ 592,500	
Overhaul on 625,500 yards at 25 cents	156,375	
Dam and tail-race complete		$ 2,087,681

The over-haul is estimated as extra cost of borrowing the material used for power canal, dam and navigation canal, from the tail-race.

COMPARISON.	NASHVILLE PROJECT.	MIDDLE LOCK PROJECT.
Dam and canal	$ 2,443,143	$1,338,806
Dam, canal and race	3,504,693	2,087,681

The head will be increased by the amount of fall in power canal above new entrance, or by 0.6 to 1.0 foot according to stage.

The same modification will apply to location of basin as in project discussed.

The data in regard to material required to raise guard-bank of navigation canal is uncertain. The project can be modified so as to do away with the navigation canal above Middle Lock, by rebuilding this lock to the proper elevation.

This scheme does not permit progressive development except as to tail-race.

The above estimate is to be considered as a trial estimate only.

3—DAM AT LOWER CHAIN.

The west end to be ⅔ mile above south end of Lower Lock; the east end to be ¼ mile below Cheney Creek; Cheney Creek to be diverted below dam.

The dam crest is to be at same elevation as at Nashville and 28 feet high above lower end of roll-way, the crest to be 7,000 feet long. It is to be located in two slants with angle of 60 degrees up stream, the heel of the slants to be connected with either shore by walls, about 1,000 feet long to west shore and 1,200 feet long to east shore.

The navigation canal is to be abandoned and a single lock constructed through the west wall. A guard bank is to be constructed from the west heel of the dam to the bridge and the area behind same deepened for navigation and for a tail-race. A similar guard-bank is to be constructed from the east heel down stream and a tail-race cut behind same. Power stations will be placed on each side. The rail-way from Nashville to Keokuk will be re-located.

The trial estimate is as follows:

Dam, 7,240 feet		$ 979,947
Excavation 37,120 yards at $1.00	$ 37,120	
Concrete, 134,574 yards at $5.50	740,157	
Coffer-dam and miscellaneous $8.00 per foot	57,920	
Shore walls, 35,400 yards at $3.75	132,750	
Diverting Cheney Creek, 16,000 yards at 75 cents	12,000	
Tail-race, west side, 400 feet wide, 400,000 yards at 75 cents	$ 300,000	
Re-locating railway, right of way, etc	180,053	
Total		$ 1,460,000
Navigation lock, guide-walls, widening race, dredging old canal banks	$ 500,000	
Tail-race, east side, 250 feet wide, 550,000 yards less 150,000 yards used instructures 400,000 at 75 cents	$ 300,000	
Total, water power and navigation		$ 2,260,000

The data for much of the above estimate is uncertain.

The project for dam at lower chain makes available the entire flow without any limitation as with canal prism leading from a dam higher up stream. It also makes the gross and effective heads practically the same and therefore gives an increased horsepower.

Of the above estimate, the east tail-race can be omitted until the necessity therefor has arisen, except in so far as the material to be excavated can be used in construction. Otherwise, progressive development is not permitted.

4—POSSIBLE HORSE-POWER.

New England practice develops the water supply for eight months and supplements the deficiency of the remaining months by steam power.

In the twenty-year period, 1881-1900, the Nashville gauge reading has been below 1.6 feet for an aggregate of 2,414 days, an average period of 120.7 days per year, or practically four months. The equivalent volume of water for the above gauge height is 37,600 second feet and the effective fall for same on the Nashville dam project 25.9 feet. The effective horse-power may be taken at 88,500. The minimum (standard low water) is taken at 50,000. The surplus is therefore 38,500 horse-power for eight months, decreasing to nothing during the remaining four months of the average year.

It is assumed that the area of the pond above dam is sufficient to store the water so that a demand varying through the 24 hours can be met to the full measure of the horse-power hours. It is also assumed that non-working days and other causes will deduct one-sixth of the horse-power hours. It is further assumed that the cost of steam power for such a variable condition is one cent per horse-power hour.

The supplemental steam power will then be equivalent to 38,500 horse-power for about 37½ days of the average year, judging by a trial computation of the deficiencies. This represents $9.00 per horse-power.

To develop this surplus power in connection with the Nashville dam project would require a larger canal, or the reconstruction of the navigation canal, so that it can be utilized as a power canal for all water in excess of the carrying capacity of the east shore canal.

In the case of a dam at the Lower Chain, no extra work is required other than the installation

necessary to develop the surplus for the eight months and the steam power to supplement the same for the remaining four. The cost per yearly horse-power for the surplus would then be the rental value of the extra installation, plus $9.00.

If the lower dam be considered as developing the gross head, the horse-power will then be 95,000; 55,000 constant and 40,000 surplus as above.

5—THE POND.

The Nashville dam backs low water to about midway between Dalls and Burlington, producing a pond area of some 25 square miles. With the use of power varying through the 24 hours, this constitutes highly efficient storage at times of minimum flow and greatly increases the number of horse-power hours that can be sold. The installation must, however, be adequate for the maximum demand.

A foot in depth on the reservoir is equivalent to the entire low water flow of 20,000 second feet for 9.7 hours. This permits a large over-draft for certain periods of the day, to be replenished in non-working hours.

How the actual use of power will be distributed cannot be foreseen.

Certain industries use large power in proportion to pay-roll, as in milling and metallurgical operations, and these call for 24 hour power.

Factory work with large numbers of employes will usually use power for 10 to 12 hours.

Trolley-car service takes power usually for 18 to 20 hours with largest demand in morning and evening.

The demand for lighting is heaviest for three to five hours after sunset.

Assume the constant use at 18,000 horse-power; the factory use at 40,000 for 11 hours; the trolley service to reach a maximum of 20,000, and lighting also a maximum of 20,000. Then at certain hours of the day, the uses of power will probably reach 75,000 to 80,000 horse-power, or 50 per cent in excess of the constant power of 50,000. Such a variation would affect the pond level by about six inches.

It will be seen that the use of variable powers requires a large canal that can carry much more than the average demand and that it is not practicable, in supplying a general market for power, to utilize the available horse-power hours in the low water season without the aid of a pond.

Experience alone can tell what the variation in demand will be, even after the class of industries to be served have been determined. A maximum of 50 per cent over the average is herein assumed.

6—VALUE OF POWER.

The value of steam power for a given locality is not a matter of close determination. Like railway transportation, the cost may be approximately ascertained by the auditor at the close of the season's operation.

For preliminary consideration in this portion of the Mississippi Valley, the following figures may be used for effective horse-power in efficient steam plants.

Constant powers, 8,760 hours per year, per horse-power hour	0.6c
Factory powers, taken at 3,000–3,600 hours	0.8c
Variable powers, maximum large in proportion to average	1.0c
If the use of the power is equally distributed among the three classes, the average will be	0.8c

The steam engine is located at point of use while the water-power must be transmitted. If such transmission has an efficiency of 75 per cent, 1⅓ horse-power will be required at the turbine shaft to deliver one horse-power from the motor. This means 0.6 cent per horse-power hour as equivalent cost at power station, neglecting the intermediates. The limit for generation and transmission may be taken at 0.1 cent which again reduces the basis to 0.5 per horse-power hour on the turbine shaft. A miscellaneous market demands 50 per cent of extra installation as hereinbefore noted, but central station working does not require the excess involved in the aggregate for local steam plants. With such excess it is assumed that five-sixth the total horse-power hours can be sold. With less than this excess, the salable horse-power hours are taken at five-sixth of two-third, or five-ninth the limit of the installation.

If a part of the power is used directly at or near the power station, as in the case of local steam plants, the basis will be about 0.65 cent on the same rating.

For a mixed case of local and distant use, it will not be safe to take the equivalent value at over 0.5 cents at the turbine shaft. Nor will it be safe to take the salable horse-power hours above 5,000 per year for one horse-power of installation, without special knowledge of proposed use.

What charge water-power will bear is a matter for estimate in each case.

APPENDIX NO. 1.

Discharge in 1,000 Cubic Feet Per Second for Nashville Gauge And the Equivalent Stage at Keokuk. (Seddon.)

GAUGE.	DISCHARGE.	KEOKUK GAUGE.
.0	19.0	–1.26
0.1	20.0	–0.99
0.2	21.0	–0.72
0.3	22.0	–0.45
0.4	23.1	–0.18
0.5	24.2	–0.08
0.6	25.3	0.34
0.7	26.5	0.60
0.8	27.7	0.86
0.9	28.9	1.11
1.0	30.1	1.36
1.2	32.5	1.81
1.4	35.0	2.17
1.6	37.6	2.51
1.8	40.2	2.86
2.0	43.0	3.20
2.5	50.1	4.07
3.0	58.2	4.93
3.5	67.3	5.79
4.0	77.3	6.65
4.5	88.1	7.51
5.0	90.8	8.37
5.5	112.7	9.23
6.0	126.8	10.09
6.5	142.0	10.96
7.0	158.1	11.82
7.5	175.2	12.68
8.0	193.6	13.54
8.5	213.2	14.40
9.0	233.6	15.26
9.5	254.6	16.12
10.0	276.1	16.99
10.5	298.1	17.85
11.0	320.7	18.56
11.5	343.9	19.16
12.0	367.7	19.67
12.5	392.1	20.14

APPENDIX NO. 2.

Discharge Curves; or Flow Levels. (Seddon.)

DISCHARGE 1,000	HANNIBAL GAUGE.	KEOKUK GAUGE.	NASHVILLE GAUGE.	BURLINGTON GAUGE.
25	0.85	0.23	0.57	0.63
30	2.04	1.37	1.01	1.62
35	2.86	2.15	1.34	2.29
40	3.56	2.83	1.78	2.87
50	4.83	4.05	2.50	3.93
60	5.91	5.09	3.09	4.82
70	6.88	6.03	3.63	5.63
80	7.76	6.87	4.13	6.35
90	8.57	7.64	4.58	7.02
100	9.32	8.36	5.01	7.64
120	10.68	9.66	5.76	8.76
140	11.89	10.82	6.44	9.76
160	12.99	11.88	7.05	10.67
180	14.01	12.86	7.63	11.51
200	14.96	13.77	8.14	12.30
220	15.87	14.65	8.65	13.05
240	16.75	15.49	9.14	13.78
260	17.61	16.32	9.62	14.50
280	18.45	17.13	10.09	15.19
300	19.27	17.92	10.55	15.87
320	20.02	18.55	11.00	16.52
340	20.55	19.05	11.42	17.17
360	21.00	19.50	11.84	17.80
380	21.40	19.90	12.26	18.41

APPROXIMATE.

Ice Cover.

DISCHARGE 1,000	HANNIBAL GAUGE	KEOKUK GAUGE.	NASHVILLE GAUGE	BURLINGTON GAUGE
20	2.90	2.19	1.41	2.33
30	4.55	3.78	2.33	3.71
40	5.75	4.94	3.01	4.69

The above flow levels rest on observed discharges at Burlington in 1879 up to 100, and at Hannibal in 1880-1, up to 270.

Ice values are approximate general levels for ordinary ice cover observed at Hannibal and transferred by gauge relations. They are to be used with caution.

For measured discharges, see "Discharge Observations, 1838-94," Miss. Riv. Com.

APPENDIX NO. 3.

Flood Expectation.

The extreme flood at any point may be deduced on the theory of normal basin ratios when known for one point.

LOCALITY.	BASIN SQ. MILES.	VOLUME 1,000	EQIVALENT GAUGE.	ACTUAL 1888.	GA'GE 1892.	U. S. ENGR.
Burlington	105,817	360,237	17.8	17.6	17.6	17.7
Nashville	111,246	372,409	12.1	12.0	11.8	12.1
Keokuk	111,246	372,409	19.77	19.6	19.2	19.6
Hannibal	129,731	412,578	22.00	23.1	20.8	21.7

The gauge at Hannibal appears to be uncertain above the bank-full stage, probably due to overflow and the conditions of the levees in the vicinity. The results are as close as can be expected in an estimate of this character.

APPENDIX NO. 4.

Discharge Over Dam With Curved Crest.

These depend on Cornell University Experiment No. 19, as reported in Transactions of the American Society of Civil Engineers, Vol. XLIV, page 284, December, 1900.

Backwater effects depend on same series as given in document, H. R. No. 200, 56th Cong., 1st Ses., page 20.

APPENDIX NO. 5.

Population, 1900.

The city population within a radius of 40 miles is as follows (1,000 and upward):

CITY.	DISTANCE, ACTUAL.	POPULATION.
Keokuk Iowa,	Local	14,641
Fort Madison, Iowa,	24	9,728
Burlington, Iowa,	43	23,201
West Burlington, Iowa,	43	1,044
New London, Iowa,	—	1,003
Farmington, Iowa,	30	1,332
Keosauqua, Iowa,	50	1,117
Kahoka, Missouri,	20	1,818
Canton, Missouri.	22	2,365
LaGrange, Missouri,	28	1,507
Hamilton, Illinois,	Local	1,344
Warsaw, Illinois,	5	2,335
Nauvoo, Illinois,	11	1,321
Carthage, Illinois,	12	2,104
Augusta, Illinois,	32	1,149
La Harpe, Illinois,	27	1,591
Colchester, Illinois,	29	1,635
Macomb, Illinois,	36	5,375
Quincy, Illinois,	39	36,252
Camp Point, Illinois,	40	1,260
Cities over 1,000, 20		111,672
Villages, 40		17,661
Rural		112,378
Total, 5,027 square miles		241,711

RECAPITULATION.

	CITIES		VILLAGES		RURAL
	NO.	POPULATION.	NO.	POPULATION.	POPULATION
Iowa	7	51,616	9	4,275	32,341
Missouri	3	5,690	7	2,895	23,523
Illinois	10	54,366	24	10,491	56,514
Total	20	111,672	40	17,661	112,378

Outside the 40 mile limit are a number of considerable cities, the largest of which is Hannibal with a population of 12,780; distance by rail from Keokuk, 55 miles.

Distances are taken by nearest railway route, except when long detours are involved. The distance to Fort Madison and Burlington can be shortened by an overland line. Several other distances may also be shortened.

The Railway Connections are:

Chicago, Burlington and Quincy.
Chicago, Rock Island and Pacific.
Wabash.
Toledo, Peoria and Western.
Keokuk and Western.
St. Louis, Keokuk and Northwestern.
Santa Fe, running north of Keokuk.

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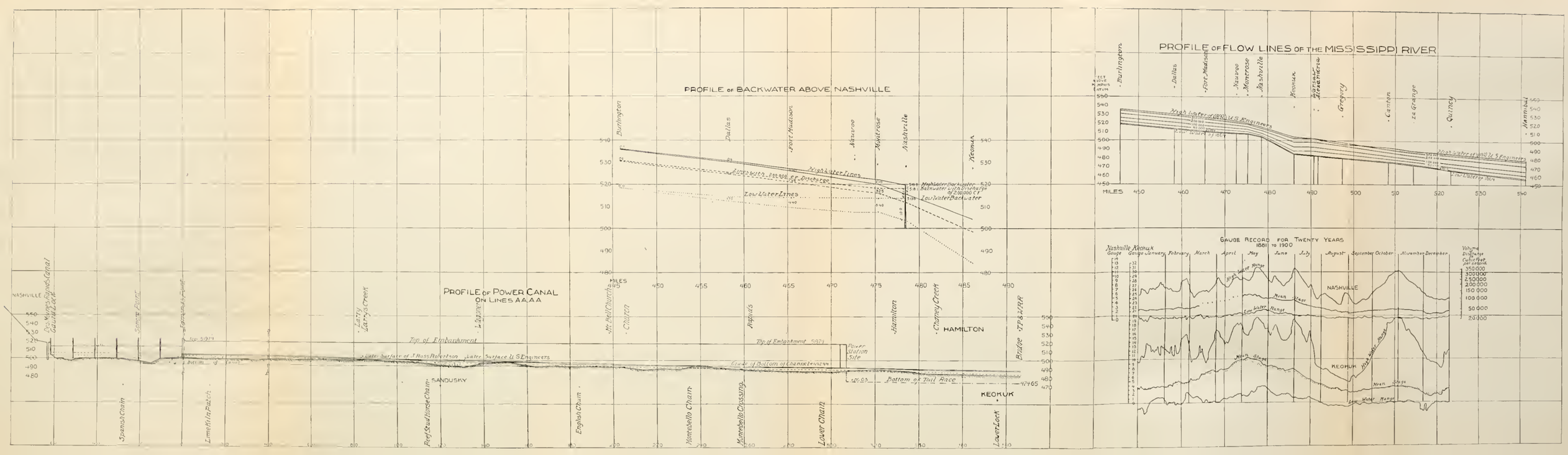
PROFILE of BACKWATER ABOVE NASHVILLE
Burlington
Dallas
Fort Madison
Nauvoo
Montrose
Nashville
Keokuk
High Water Lines
Low Water Lines
Low Water Backwater
PROFILE of POWER CANAL ON LINES AAAA
NASHVILLE
Top of Embankment
Water Surface of J. Ross Robertson
Water Surface U.S. Engineers
Guide of Bottom of Canal
Bottom of Tail Race
Power Station Site
HAMILTON
KEOKUK
SANDUSKY
Spanish Chain
Limekiln Patch
Reef Sandstone Chain
English Chain
Monroeville Chain
Monroeville Crossing
Lower Chain
Lower Lock
Bridge T.P.&A.R.R.
Mt. Pelt Church
Clayton
Rapids
Hamilton
Cherney Creek
Larry's Creek
PROFILE of FLOW LINES of the MISSISSIPPI RIVER
Burlington
Dallas
Fort Madison
Nauvoo
Montrose
Nashville
Keokuk
Warsaw
Gregory
Canton
La Grange
Quincy
Hannibal
High Water of 1892 U.S. Engineers
Low Water 1864
MILES
GAUGE RECORD FOR TWENTY YEARS 1881 to 1900
Nashville Gauge
Keokuk Gauge
January
February
March
April
May
June
July
August
September
October
November
December
High Water Range
Mean Stage
Low Water Range
NASHVILLE
KEOKUK
Volume Discharge Cubic Feet per second

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